

Distributed Simulation Testing for Weapons System Performance of the F/A-18 and AIM-120 AMRAAM

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I. Abstract

The Naval Air Warfare Center Weapons Division has established a long range, real-time link between the F/A-18 Weapons System Support Facility (WSSF) at China Lake, CA and the AIM-120 Hardware in the Loop (HWIL) laboratory at Point Mugu, CA. The link was established in response to a fleet demand for information on the total weapons system performance of the Hornet and AIM-120 sub-systems in an electronic jamming environment, since AIM-120 performance is very dependent on the quality of the guidance data link provided by the host aircraft. In an effort to minimize costly flight testing, the link concept was developed to obtain actual (vice simulated) aircraft radar performance and data link updates in order to more accurately assess overall performance of the aircraft/missile system.

II. Introduction

The addition of the AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM) to the F/A-18 Hornet represented a significant increase in the warfighting capability of the aircraft. Current and evolving threats make a credible beyond-visual-range launch-and-leave missile an imperative to acceptable combat survivability in the modern air-to-air arena. Not only does the AMRAAM bring the aircraft a fast missile with good range and kinematic capability; it also brings to the table significant upgradability through software enhancements. As electronic attack threats evolve and are exploited, the missile software is enhanced to counter the new capabilities of potential adversaries. Significant simulation testing of the missile performance is done during new software development, but little testing of the total aircraft/missile systems performance together is performed by the developer.

The AMRAAM design is dependent upon the quality of aircraft data link for target acquisition. To address this dependence, a series of tests to quantify and

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characterize the total weapons system performance in an electronic attack environment was clearly needed. This need was answered through a program that is jointly funded by the AMRAAM and F/A-18 program offices.

In recent years, there has been much discussion, planning, and experimentation in the area of distributed simulation. Under this concept, simulations of complex interactive systems that are located in separate buildings or at different geographical locations are linked electronically. One application of this concept is the connection of missile and aircraft simulations for the purpose of determining system interface issues and performance capability. Within the Naval Air Warfare Center, the AMRAAM HWIL facility at Point Mugu has been working on an electronic link with the F/A-18 Weapon System Support Facility at China Lake. The WSSF is part of the F/A-18 Weapon System Support Activity. In direct response to budget cuts and the significant cost of flight test the concept of linking the F/A-18 and AMRAAM labs was born.

III. Background

3.1 AMRAAM:

The AIM-120 is an advanced medium range missile that provides the aircraft with a beyond visual range launch-and-leave capability. It is a \$6 Billion Acquisition Category 1D Joint Air Force-Navy program with the Air Force acting as the executive service. Hughes Missile Systems (now Raytheon) is the prime contractor and developer of the missile. The missile is 12 feet long and weighs 345 pounds. Figure 1 shows the basic layout of the missile. The missile is tail controlled, highly maneuverable and has excellent average velocity over the time of flight. An onboard X-band radar that operates in both high and medium pulse repetition frequencies provides terminal guidance.

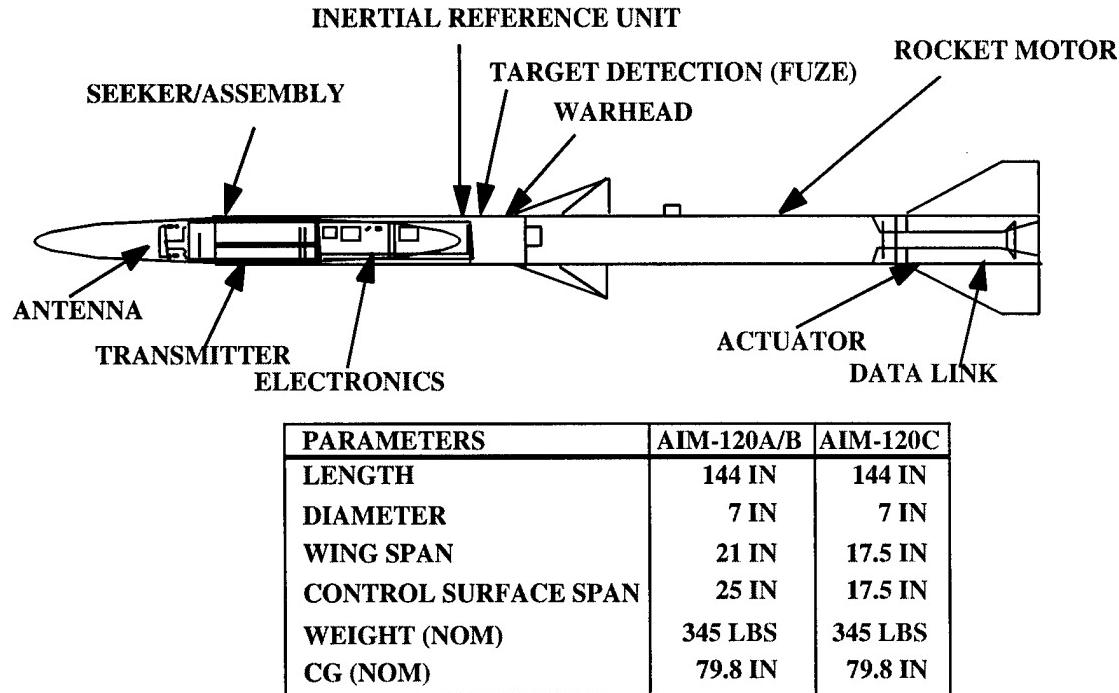


Figure 1
AMRAAM Configuration

AMRAAM has undergone significant changes since first developed and is currently being produced in the AIM-120C clipped wing version for the U.S. and the AIM-120B version for foreign sales. The clipped wing modification was required for internal carriage on the F-22 aircraft. Currently, a new rocket motor with 5 inches of extra propellant, a new warhead with more fragments and a new target detecting device are in development. Figure 2 shows the clipped wing version of the missile.



Figure 2
AIM-120C Clipped Wing

The AMRAAM operates in several modes. The preferred launch mode is the Command Inertial mode in which the missile receives targeting instructions from the

aircraft through the use of an RF data link which is updated every 0.5 to 1 second depending on the launch mode of the aircraft radar. Inertial Active is a complete launch and leave mode in which the AMRAAM guides to an inertial point provided to the missile pre-launch with no updates during flight. Terminal guidance is provided by the missile's onboard radar. The missile is also capable of sorting multiple targets and picking individual targets for each missile launched against an unresolved group of targets. The missile can also be launched in a home on jam mode in a noise jamming environment and a visual mode when no radar targeting is provided to the missile. Figure 3 depicts the various launch modes:

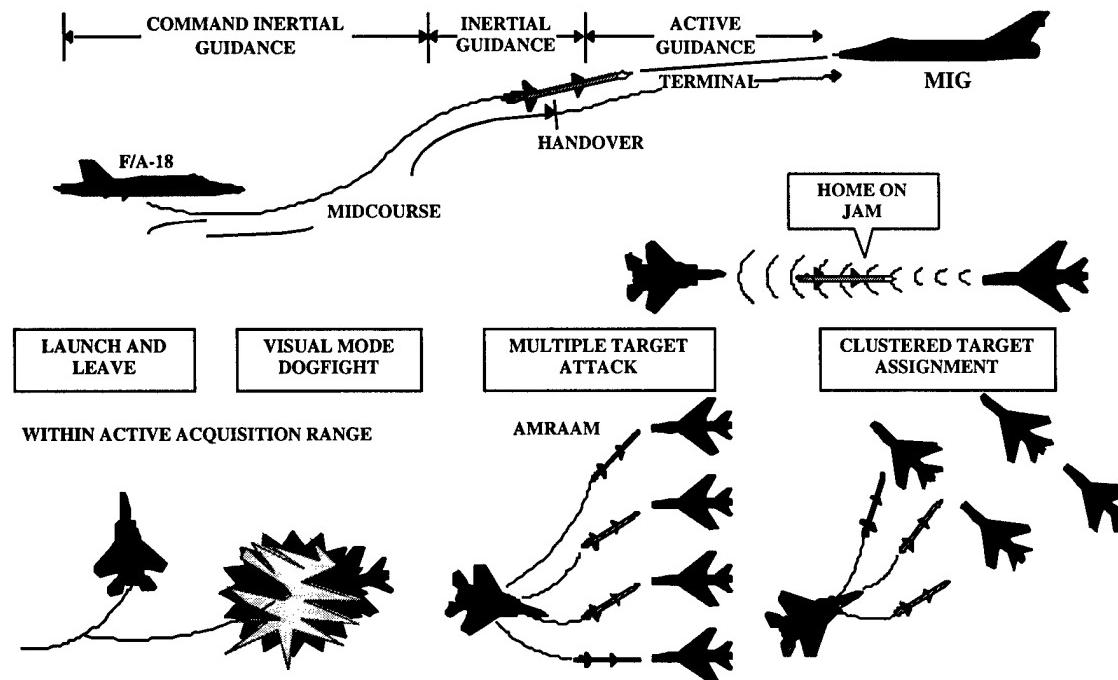


Figure 3
AMRAAM Launch Modes

The design of AMRAAM makes it very dependent on the quality of targeting information provided by the host aircraft. The requirement for the missile to be very selective, in other words to hit only the desired target and not one in close proximity, forces the missile to follow instructions from the host aircraft very carefully. Targeting information is provided by way of a one-way Radio Frequency (RF) data link that provides the missile with target information. Since the missile very closely follows host radar instructions, bad instructions will significantly reduce the effectiveness of the missile. Electronic jamming can cause significant degradation to the tracking ability of the host radar and thus degrade the quality of the targeting data passed via the data link. The AMRAAM searches a volume, known as the uncertainty volume, around the data link

provided point. If the targeting data is bad enough the target will never be seen by the missile, even if it's own robust Electronic Protection capabilities would allow it to track and guide on the jamming target. This design philosophy is the key to the necessity of the test series.

3.2 Hardware in the Loop:

The AMRAAM Hardware-In-the-Loop (HWIL) lab located at the Naval Air Warfare Center in Point Mugu, CA provides the capability to simulate real-time missile flight scenarios from launch to target intercept. Housed in a 40' wide x 35' high spherical backplane anechoic chamber, the lab components include actual AMRAAM missile hardware, a CARCO flight motion table, computer-controlled Radio Frequency (RF) sources utilized to simulate maneuvering targets and electronic countermeasures, and computer systems that provide the real-time Six Degree-of-Freedom (6DOF) simulation. A brief description of each follows:

- The AMRAAM missile hardware consists of the RF sensor system, guidance section and the telemetry section.
- The RF seeker is mounted on the CARCO 3-axis flight table, which simulates missile flight dynamics by providing roll, pitch and yaw motion. The CARCO table is positioned on a vibration isolated concrete pillar to prevent table dynamics from affecting the RF array.
- The RF source is a horn array of dual-polarized RF horns (vertical and horizontal polarization) that are positioned on the wall opposite the missile seeker. Through radiation emissions, the four target signal generators and three target positioning systems (TPS) provide the capability to simulate multiple targets, electronic countermeasures (ECM), Mainlobe Clutter (MLC) and Altitude Return (AR). The array of horns are positioned exactly 31.5 feet from the missile seeker to present a far field planar wave to the seeker. Figure 4 shows the RF horn array and flight table.

- A. The RF sources can be arranged in the following ways:
 1. One or two complex targets (including amplitude scintillation and angle glint) with or without ECM with or without Jet Engine Modulation (JEM), MLC and AR.
 2. One or two complex targets with or without ECM with or without JEM with a Stand off Jammer (SOJ) and either MLC or AR.
- B. The system is expandable to four more target signal generators (TSG) and five more target positioning systems for a total of eight TSGs and TPSs. This would allow six complex targets with ECM and JEM or four complex targets with ECM, JEM, MLC, and AR.

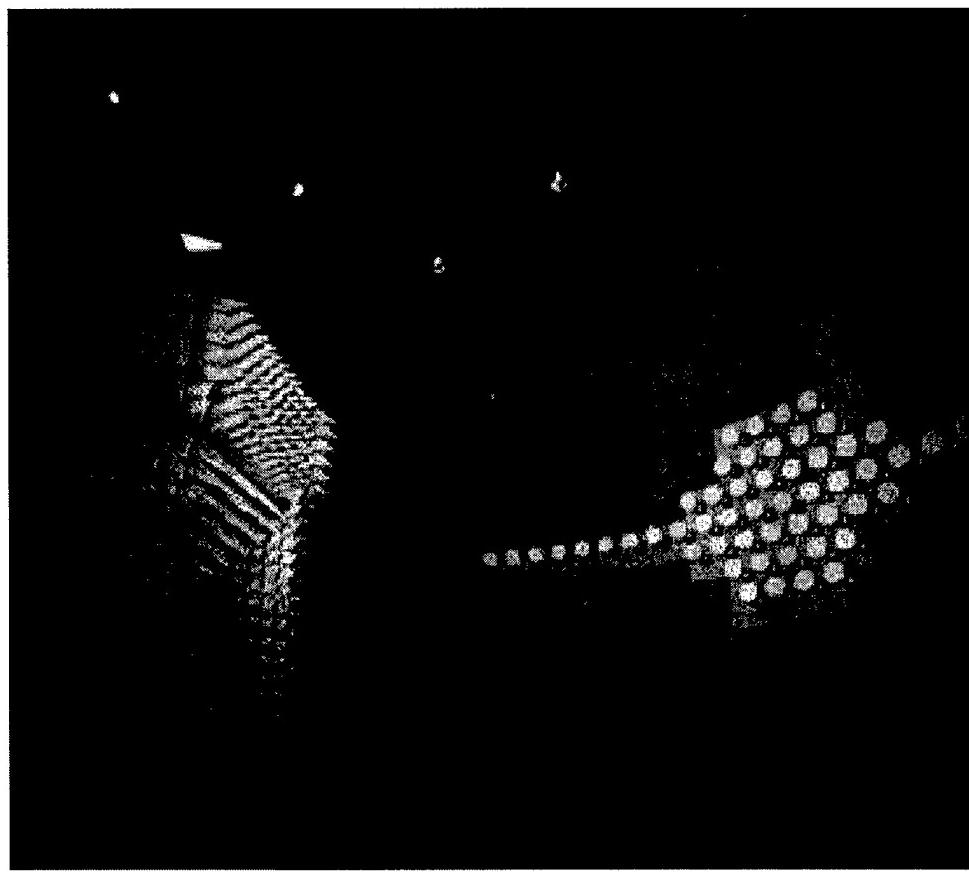


Figure 4
HWIL RF Horn Array

- Real-time simulation and modeling are provided by eight Intel i860 simulation computers operating in parallel, 2 SUN SPARC host computers, and a separate VME-based i860 data capture computer. In addition, the simulation system includes a Silicon Graphics (SGI) 3D computer used to display flyout graphics and an IBM compatible computer in conjunction with a Digital PDP-11 which control the simulated launch of AMRAAM. Collectively, all 14 computers are known as the Simulation Computer System (SCS). The 6DOF running on the SCS receives data from the AMRAAM missile that is stimulated by RF emissions from the array, then outputs kinematics control signals to the 3-axis flight table. The SCS also simultaneously drives the RF sources to replicate dynamic targets and the changing countermeasure and clutter environment. Figure 5 shows a basic functional diagram of the HWIL facility:

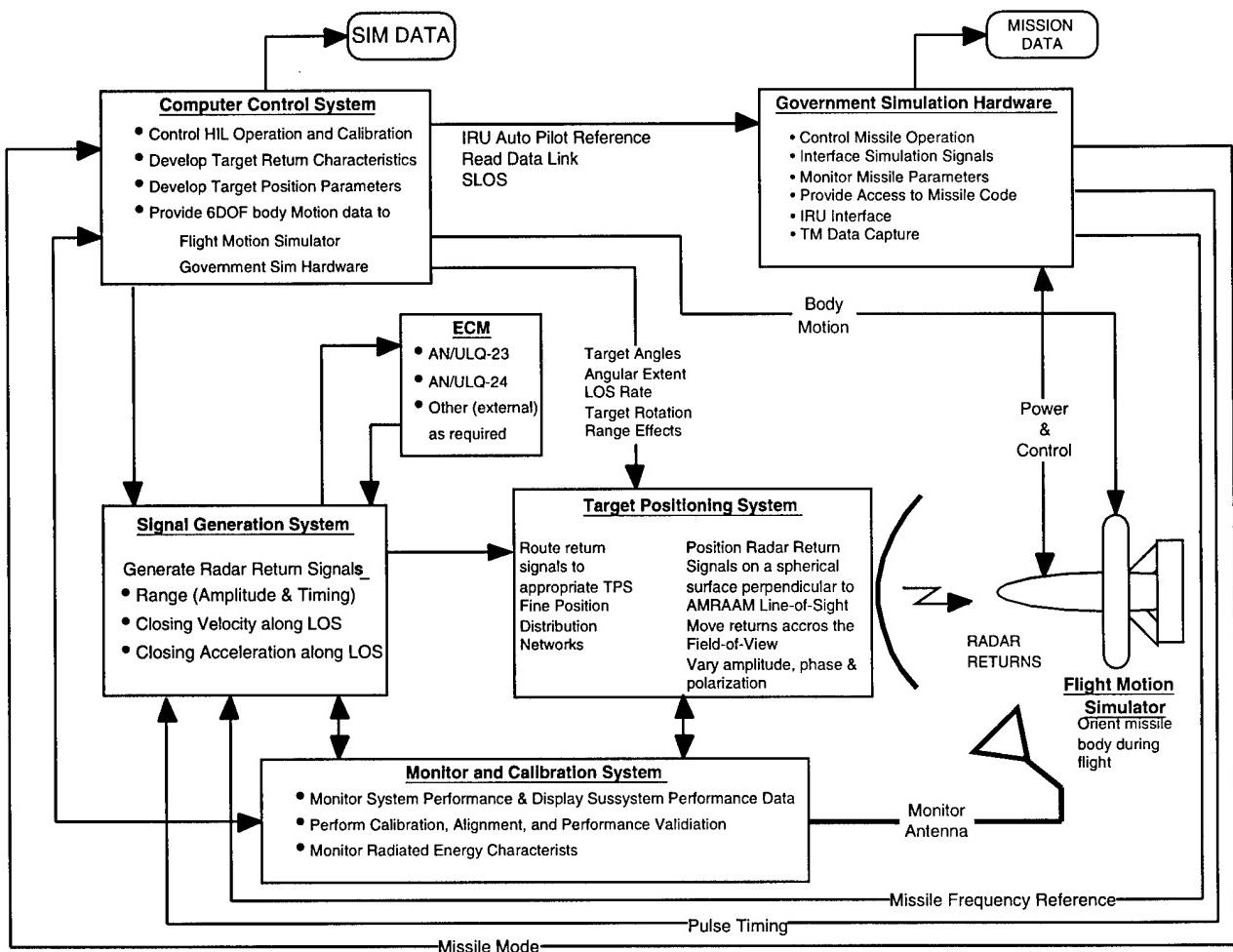


Figure 5
HWIL Facility Diagram

The primary purpose of the HWIL is to evaluate the performance of the AMRAAM missile seeker and guidance subsystem. The lab is utilized to perform both pre-flight and post-flight simulations for all planned F/A-18 flight test scenarios as well as AMRAAM specific testing and system level weapons system performance testing. A critical validation of the laboratory was performed to characterize technical performance parameters and identify critical limitations of the HWIL in order to identify simulation artifacts in test results.

The AMRAAM HWIL has recently gone through a major upgrade program. The aforementioned RF horn array, target signal generators, target positioning system, and the simulation computer system were all part of the upgrade. In addition, the upgrade included a new mainlobe clutter model, JEM model, and very robust calibration and diagnostic software. This upgrade provides the AMRAAM HWIL with the capability to be a valuable asset for AMRAAM activities for the foreseeable future.

3.3 F/A-18 WSSF:

The Navy is performing overall improvements of the F/A-18 weapon systems to keep pace with the evolutionary changes in digital technology, technical obsolescence, and operational requirements. The F/A-18 Weapon System Support Activity (WSSA) designs, develops, maintains, and operates integration and test facilities used in the development, test, evaluation, and Fleet support of the F/A-18 weapon system.

The F/A-18 WSSA Facility is the primary tool used to perform life-cycle maintenance of the F/A-18 weapon system embedded computer systems and associated Operational Flight Programs. It is comprised of a group of hardware-in-the-loop integration and test laboratories used to perform development testing, safety-of-flight testing, verification and validation testing, quick response investigations of Fleet reported problems, correction of deficiencies, investigation and evaluation of changes, and integration and test of new technology and weapons. These laboratories are continually evolving to support past, present, future, and foreign versions of the F/A-18 weapon system. Figure 6 shows the basic architecture of the WSSF facility.

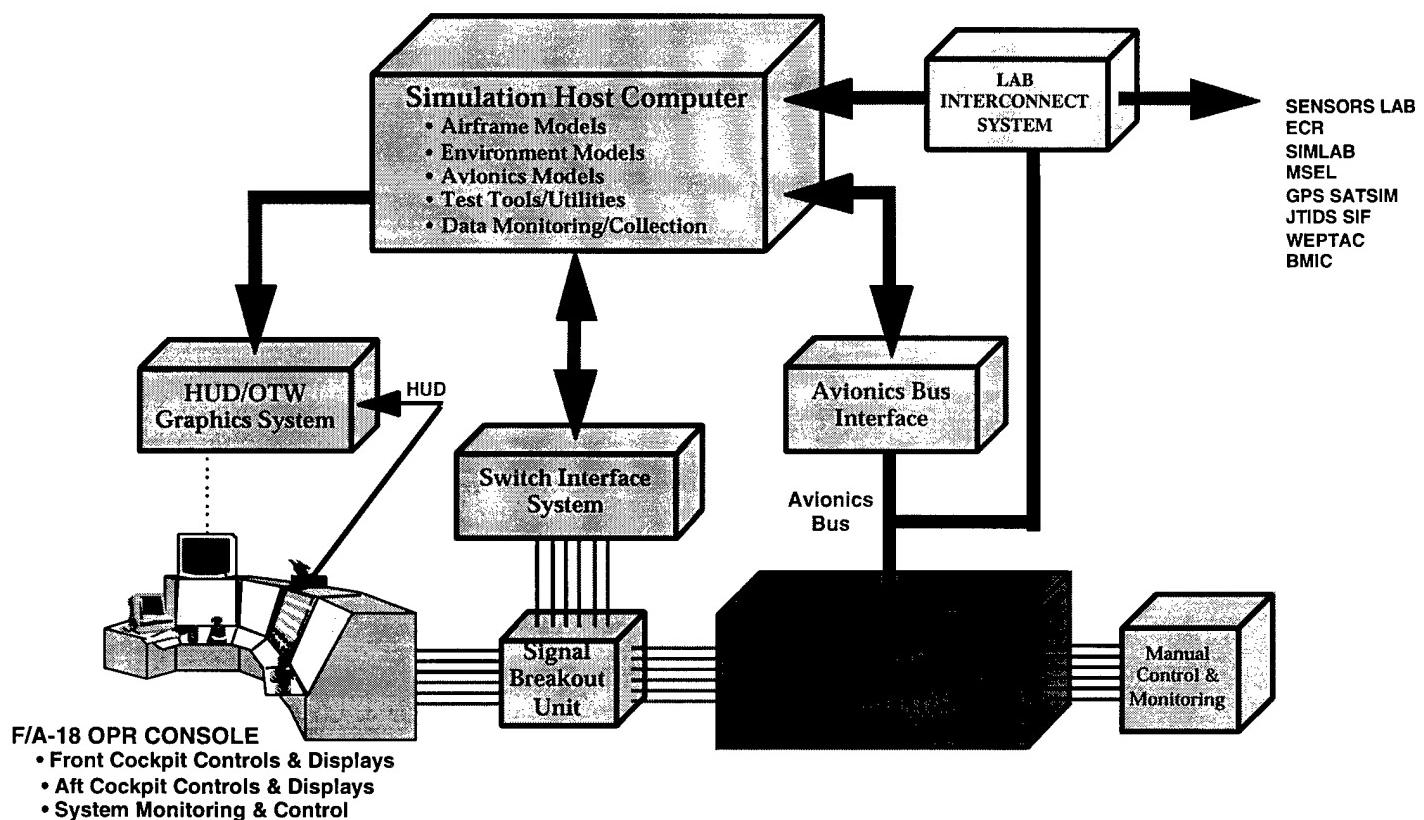


Figure 6
F/A-18 WSSF Architecture

Each laboratory uses real-time simulation to stimulate actual weapon system elements into "thinking" they are flying in a fully operational environment. Weapon system elements not desired in the laboratory, considered ineffective in a laboratory environment or unavailable are simulated using real-time mathematical models to affect a complete system during testing. On-line and post-test data monitoring and analysis tools provide in-depth visibility to assess system operation and performance.

Core mission system avionics and sensor laboratories (Radar, FLIR, EW, etc.) are combined to satisfy a full range of test requirements. The primary key features of the WSSA facilities are:

Flight Modes - Provides man-in-the-loop, profile generator, canned scenario, and precise manual control modes of dynamic flight. Actual cockpit controls and displays used with dynamic out-the-window scene generation provide realistic real-time test scenarios.

Tactical Environment - Flight system simulates platform dynamics, tactical environment, and user-selectable weapons system elements to support scenarios with combined real and/or simulated avionics.

Weapons - The use of real weapons for ground checks and simulated weapons for dynamic captive carry, launch, and post-launch engagements.

Control, Monitoring, & Data Collection - Dynamic scenario setup and control, on-line data/event monitoring, and real-time data collection for post-test analysis. Real-time non-intrusive logic and data sampling.

Flight Test Data Playback - Playback of instrumented aircraft flight test data in the laboratory to recreate problems and validate corrections.

Dynamic Lab-to-Lab Links to Other Facilities & Ranges:

- Sensor Lab Links for Radar, FLIR, EW, and RECCE Sensor Integration
- Hardware-in-the-Loop Missile Lab Links for Missile Integration
- Electronic Combat Range Link for Live-Threat EW Testing
- GPS Satellite Simulator Link for GPS Receiver Integration
- Range Control Center Link for Real-time TSPI & Future TM Data
- NRaD System Integration Facility Link for MIDS Link-16 Integration & Test

Each laboratory is comprised of a digital simulation system with embedded processors for associated weapon system data path interfaces, operator console (engineering cockpit), computer visualization, performance and monitoring system, and associated fighter aircraft simulation software. All aspects of the F/A-18 master modes are supported including navigation, air-to-air weapon delivery, and air-to-ground weapon

delivery. Simulation functions include F/A-18 aircraft dynamics, environment (earth, atmosphere, and targets); model substitution for selected weapon system elements, dynamic out-the-window computer graphics, and specialized test functions. Figure 7 shows the relationship of the various F/A-18 development labs.

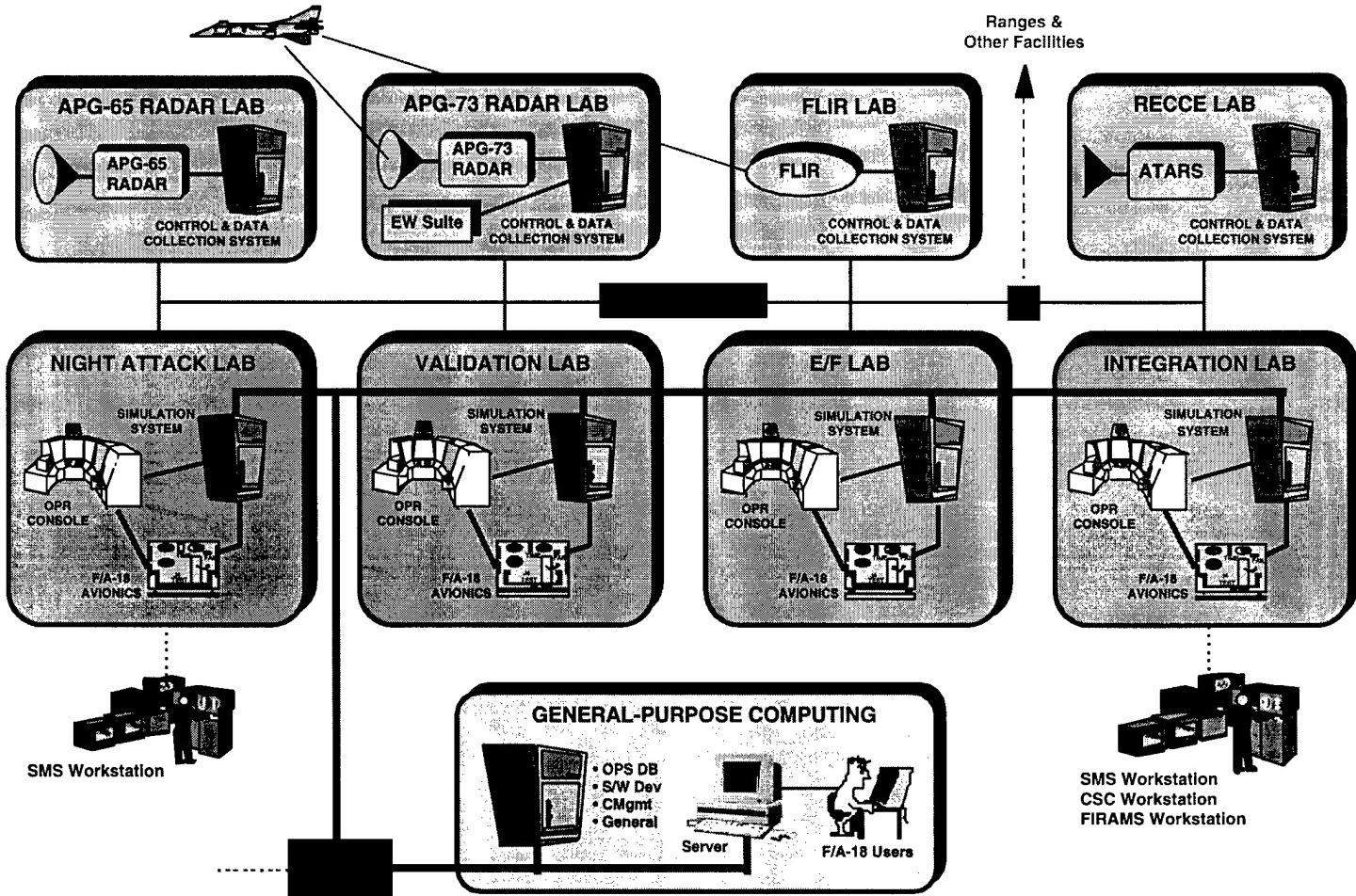


Figure 7
F/A-18 WSSF Lab Relationships

IV. Discussion

4.1 EPTWG:

In direct response to fleet requests for detailed weapons system performance information for the FA-18/AMRAAM combination, the F/A-18 and AMRAAM program offices funded a series of flight and simulation tests to gather information to meet fleet needs. Threats were chosen by the joint Navy-Air Force Electronic Protection Threat Working Group (EPTWG) which utilized inputs from the National Air

Intelligence Center and the EW Threat Simulations group at the Naval Air Warfare Center in Point Mugu, CA. The EPTWG consists of operational fighter aircrew from the Air Force, Navy and Marine Corps and is sponsored by the AMRAAM Joint Systems Program Office at Eglin AFB, FL. Threats were prioritized by evaluating threat effectiveness, proliferation and the likelihood of encountering them in combat. The EPTWG test series is currently in its third year and consists of flight testing of the aircraft radar against selected threats, AMRAAM Captive Equipment (ACE) flights against the same threats, Hardware-in-the-Loop simulation and digital simulation.

4.2 EPTWG Test Description:

The fidelity of test data is directly proportional to cost. The highest cost operation is, of course, a live launch but the data obtained is generally very enlightening. Captive flight testing is the next best thing and typically costs only about 25% of a live op. HWIL testing is the next highest fidelity test method. HWIL tests can be used to parametrically examine the affect of complex scenarios and environments. The EPTWG test series seeks to optimize available resources to obtain the highest fidelity data versus the most important threats and obtain the greatest volume of test data possible within budget constraints. Figure 8 depicts the cost relationships.

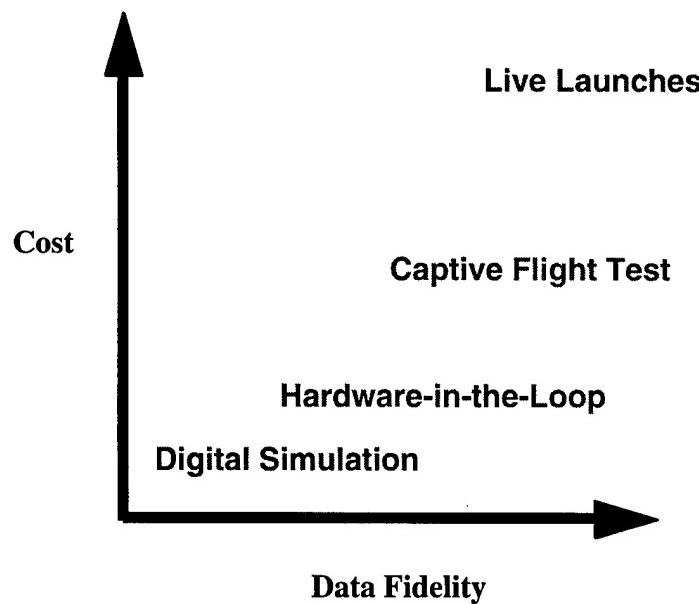


Figure 8
Cost versus Data Fidelity

The EPTWG test series includes a combination of flight test, Hardware in the Loop tests and digital simulation. Flight testing is performed in two phases: the first is funded by the F/A-18 and consists of radar evaluation flights against prioritized threats assigned by the EPTWG. The aircraft are heavily instrumented and extremely detailed radar performance data versus various jamming waveforms is obtained. The aircraft either carry AMRAAM Integration Test Vehicles (ITV) or Missile Message Units (MMU) to capture AMRAAM data link messages during simulated launches. Time, Space and Position Indications (TSPI) are compared with aircraft supplied data link to determine the accuracy of the data link messages. The captured in-flight data link is placed in a database and utilized for both HWIL and digital simulations.

The second phase of flight testing is funded by the AMRAAM program and consists of flights against the highest priority threats. Flights are performed with the AMRAAM Captive Equipment (ACE) pod that contains actual missile components and environmental conditioning to allow for multiple launches. The aircraft treats the ACE pod as an actual live missile and provides all support including postlaunch data link. After simulated launch, the ACE pod receives the data link and, when in range of the target will activate its onboard transmitter and attempt to acquire the target. The ACE pod utilizes the same tactical software as an actual missile. All missile functions are captured and transmitted real time through secure telemetry channels. Post-flight analysis includes a detailed analysis of aircraft data link, missile functioning and trackfile activity and TSPI comparison of actual versus system targeting information. ACE flight data is utilized post-flight to both help verify simulation validity and to improve fidelity of the data link database.

A majority of the EPTWG test series is performed on a Sun or PC workstation utilizing a 6 degree of freedom digital simulation that emulates aerodynamic performance and missile seeker and guidance section performance. Dynetics developed the digital simulation program under contract to the AMRAAM program office. Data link files from representative flight tests are utilized in the simulation to improve fidelity. Post-flight simulations are run to replicate actual flight test parameters and the results are compared to help validate simulation accuracy.

The HWIL lab is utilized to test actual jamming sources versus the missile in a variety of scenarios. In the past, canned aircraft data link values were used to perform testing. Presently, if pre-recorded data link from actual flight test sorties is available, it is utilized and has improved the fidelity of test results significantly. Testing both duplicates those performed in flight test and expands the test matrix to include those jamming scenarios for which flight test funding was not available. The preceding section carefully detailed the functioning of the HWIL facility.

V. F/A-18 and AMRAAM Link

The ultimate goal of the link is to develop a system performance evaluation tool for all versions of AMRAAM and AMRAAM-capable F/A-18 aircraft. This linked system will be used to evaluate basic software logic and interface functionality, and to determine system capability in complex Electronic Countermeasure (ECM) environments. To accomplish this, the missile and aircraft/radar simulations must have a fully functional real-time interface, and must be presented with time-synchronized and functionally equivalent Radio Frequency (RF) environments. The missile and aircraft/radar simulations must be of sufficient fidelity for both F/A-18 and AMRAAM programs to accept the results as flight-representative. Once this capability has been achieved, the combined link can be used to spot check actual flight results, and to supplement or replace some flight test missions for programs such as the Operational Tactics Guide (OTG) and Electronic Protection Threat Working Group (EPTWG) evaluations.

Initial work on the idea was begun in 1996 and initially consisted of a simple kinematic link implemented over a 150 plus mile fiber optic link. The kinematic link placed the HWIL missile in the same orientation as the aircraft at launch. For example, if the aircraft were in a turn the missile body in the HWIL would roll to match orientation to the aircraft. Prior to each linked run, a mutually agreed upon test scenario was chosen. The WSSF initiated a HWIL missile launch at a predetermined range to the target. The HWIL recognized the launch command and then passed canned umbilical and data link information to the missile that were specific to the chosen scenario.

The current HWIL/WSSF link provides for real-time kinematic interaction between the missile and aircraft simulations. In addition, a HWIL missile launch can be initiated from the aircraft cockpit simulation at the WSSF. In the current configuration, umbilical traffic and RF data link information are passed over a separate ethernet link which emulates MIL-STD-1553 format. The ethernet link allows passage of bi-directional real-time umbilical traffic and one way passage of aircraft data link information while the missile is in simulated free flight.

5.1 HWIL/WSSF Link System Architecture:

The hardware at both sites is connected by a fiber optic ethernet link over which aircraft and missile dynamics are passed. Aircraft supplied data link targeting messages are also passed over the ethernet link. A separate RS-232 Integrated Services Digital Network (ISDN) connection is established over which 1553 umbilical prelaunch messages, aircraft release consent and the interlock return confirming missile readiness to launch and the actual missile launch. The ISDN link is controlled by PC's at each location emulating a 1553 bus. Both ISDN and ethernet connections are encrypted. Figure 9 shows the basic relationship of the labs and link implementation.

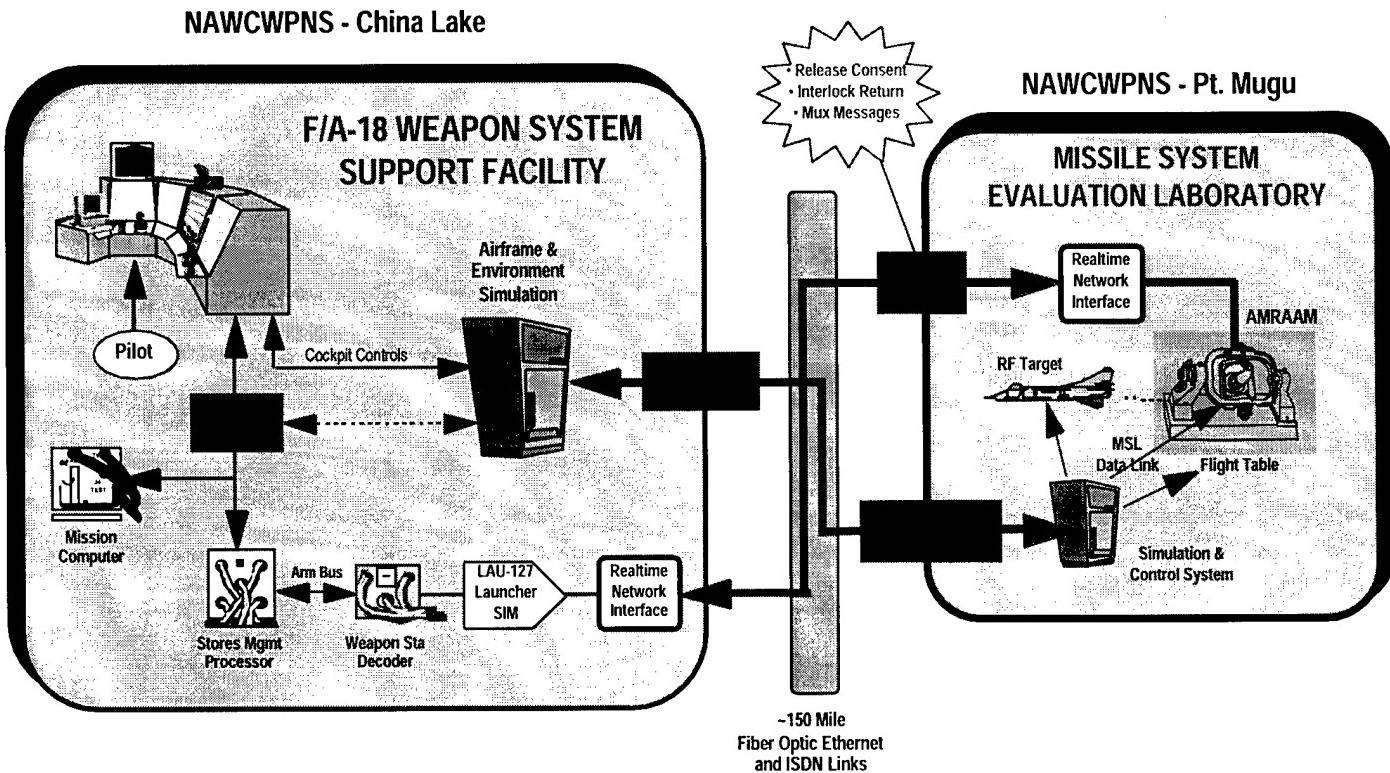


Figure 9
WSSF and HWIL Link Concept

5.2 Future Enhancements:

The system as currently implemented is quickly maturing towards utility for system level testing. Currently, efforts are underway to both improve the existing implementation and increase capabilities in two critical areas. The first is the capability to use the actual radar in the WSSF to present real time targets to the AMRAAM lab. The second critical area is the capability to present matched RF and jamming environments at both labs.

The capability to use the actual radar in the WSSF is the easier of the two remaining hurdles to solve. There are two ways this capability can be implemented. The first is to simply roll the radar out and track actual airborne targets operating on the local range. This capability exists now but requires actual airborne targets, which restricts testing time and greatly increases cost. The preferred method is to synthetically inject target signals into the WSSF either at the front end of the radar or downstream at Intermediate Frequency (IF). Both of these capabilities currently exist at the WSSF but have not had data blocks implemented for the ethernet link that is required to pass the

target(s) to the AMRAAM HWIL. This represents a minor technical challenge and the capability should be available in the near term.

A significantly more complex issue is that of matching the RF environments at both sites. Several challenging technical problems must be resolved before the link will reach full functionality. The first problem is the time synchronization of the jammers at each location so that the missile and radar are presented the same environment with no data latency. The current plan is to implement a time synchronization scheme to time tag all traffic to the AMRAAM HWIL. In this implementation, data latency should not be an issue since everything will be referenced to the same time. Another possible solution is to not really worry about it since the delay should not exceed 100ms which is sufficient in most scenarios. One very difficult issue to resolve is providing a correct jammer response when the jammer is stimulated by both the F/A-18 and the AMRAAM simultaneously. Several ideas to solve this have been floated but none have as of yet, been tested. One solution is to only stimulate the jammer at the AMRAAM HWIL with multiple signals with the F/A-18 signals provided from a canned set of radar parameters that would be stored in the AMRAAM HWIL simulation and called up based on F/A-18 radar mode. Power levels would be simulated by modeling F/A-18 transmitter power out, antenna gain, radar mode and range to target. Figure 10 depicts a possible implementation.

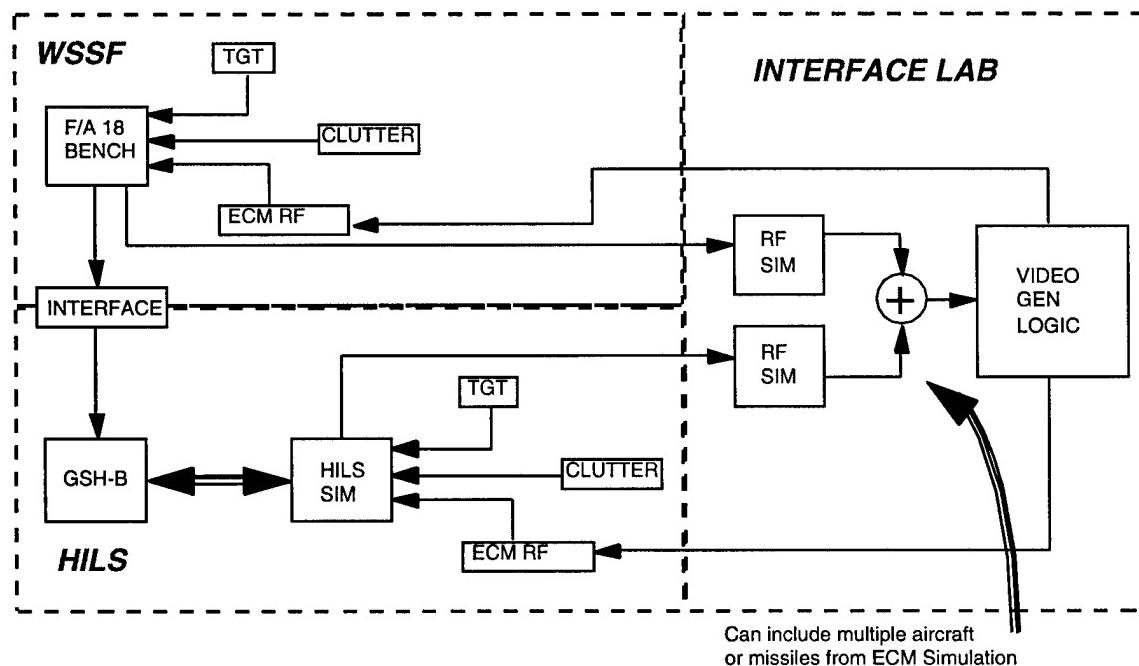


Figure 10
Proposed RF Synchronization Scheme

VI. Conclusions

The diminishing availability of funding for development and testing is forcing programs to reevaluate the manner with which they expend their limited resources. Recent advancements in computer processing power, digital simulation and telecommunications technologies have presented us with new opportunities to exploit to economize on testing and development.

Though the U.S. defense budget has declined significantly from the cold war era, the various threat systems around the world have continued to develop significant new capabilities, particularly in the arena of electronic warfare. Operational Fleet aircrews need the most up to date and accurate information available regarding the effectiveness and limitations of their weapons systems. Utilizing existing assets such as the AMRAAM HWIL facility and the F/A-18 WSSF more intelligently is critical to maximizing the weapons system data that can be collected within the available budget.

The AMRAAM HWIL and F/A-18 WSSF link takes a large step towards realizing the goal of performing economical system level testing to supplement and hopefully reduce the amount of flight testing required to satisfactorily address questions of system capabilities. The link represents a significant stride in the area of distributed simulation and an innovative use of existing simulation and development assets. The full future planned development of the link will make it not only a good tool for system level performance testing, but also for both F/A-18 Operational Flight Program development and AMRAAM enhancements and development.

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